Developing an Overwatching Fires Mission for a Team of Unmanned Ground Vehicles

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ABSTRACT

One of the goals of the U.S. Army Ground Robotics Research Program is to develop individual and group behaviors that allow the robots to contribute to tactical missions such as interdiction and reconnaissance. By using simulation tools, we are able to develop, debug and test behaviors before porting them to actual robotic platforms. Simulation tools allow researchers to evaluate behavior performance in many environments, some of which may be difficult or dangerous to duplicate in an actual hardware test. This report describes our initial efforts to develop an over watching fires mission for team of robotic platforms. The report concludes with a discussion of possible extensions to the basic tool.

KEYWORDS: ***Unmanned Ground Vehicle,*** *Tactical Behaviors, Autonomous, One Semi-Automated Forces, Reconnaissance, Scout*

1. INTRODUCTION

The primary focus of the U.S. Army Ground Robotics Research Program is autonomous mobility demonstrated primarily on the Experimental Unmanned Vehicle (XUV). As unmanned ground vehicles (UGVs) become more capable of autonomously negotiating complex cross country and urban environments, it becomes possible to develop individual and group behaviors that will allow the robots to contribute to battlefield missions with greater autonomy and reduced interaction with remote human operators.. In our previous work [1] we developed a robotic behavior for identifying and mapping a contaminated region of the battlefield. The chemical mapping mission represented a relatively simple behavior algorithm with well-characterized decision points and no direct contact with enemy (or friendly) forces. In this paper we wish to extend our behavior research by considering a different behavior algorithm, referred to as the overwatching fires (OWF) mission, in which a team of manned and armed unmanned systems interdict a road segment and prevent enemy incursion.

Tactically, the mission could be used as a part of a future combat mission with the OWF team deployed well forward of the main body. The OWF team could provide early warning as well as a measure of protection to the main body. Manned systems participate in this mission by providing mission level command and control as either direct or indirect observers. The indirect observer role offers more protection to the manned systems but adds an additional layer to the decision making process.

From a robotics research point of view, the OWF mission allows us to examine lethality issues for robots. In some sense, the concept of armed robots is not a new. In this age of smart weapons, missiles, bombs and artillery shells contain autonomous control systems that are able to reach their targets using laser or global positioning satellite (GPS) guidance. The human operator designates targets and releases the weapon. He may retain control of the weapon until the point of impact or terminal guidance may be an autonomous function of the weapon itself [2, 3]. These smart weapons are essentially single use armed robots.

The desired level of operator control required for successful operation of multiple use, ground robotic vehicles is a current research topic within the robotics community [4, 5]. In the OWF research we are interested in developing an appropriate algorithm for the mission; determining the proper level of human robot interaction; and determining the behavior and sensor requirements to respond to incomplete and inaccurate information.

This paper is a preliminary repot on the OWF research. We discuss the current OWF behavior algorithm as well as enhancements required to add robustness to the behavior. We provide some background information on the One Semi-Automated Forces Test Bed (OTB) simulation tool used to develop and test the behavior. We also include with a discussion on our extensions to OTB tool that allows us to efficiently exercise behaviors in a variety of conditions. In the final section of the paper, we discuss our on-going and future efforts to examine issues such as the effect of uncertainty and different levels of robot control on the basic OWF mission.

2. THE OVERWATCHING FIRES MISSION

The OWF mission is a behavior for a team of manned and armed unmanned systems which protects a road segment from enemy incursion. The mission is easy to describe in general terms. There are two distinct roles for team members –scout and shooters. The observers watch for enemy units on the designated road segment. Once enemy units have been identified, the shooters move into position and fire upon enemy units detected by the observers. Once the shooter has fired on its target, it moves to another firing position to await its next target. The mission continues until the enemy unit leaves the road segment; sufficient damage has been inflicted; or the OFW unit receives a new mission.

$$\mathrm{LOS}(r.m) = \begin{cases} 1, \text{if} \quad r \text{ is visible from m} \\ 0, \text{if} \quad r \text{ is not visible from m} \end{cases} \tag{2}$$

The function V has range [0, 1] with values near 1 indicating nearly all of the n points on road segment R are visible and values near 0 indication almost none of the points are visible . Figure 2 shows a section of a digital map with an example of an OFW mission area, indicated by the heavy black rectangle. The observed road segment is also shown. Figure 3 shows the associated visibility surface. Lighter regions have a better view of the road segment than darker regions. Notice that it is a highly irregular surface with areas of good visibility next to areas of poor visibility. The characteristics of the visibility

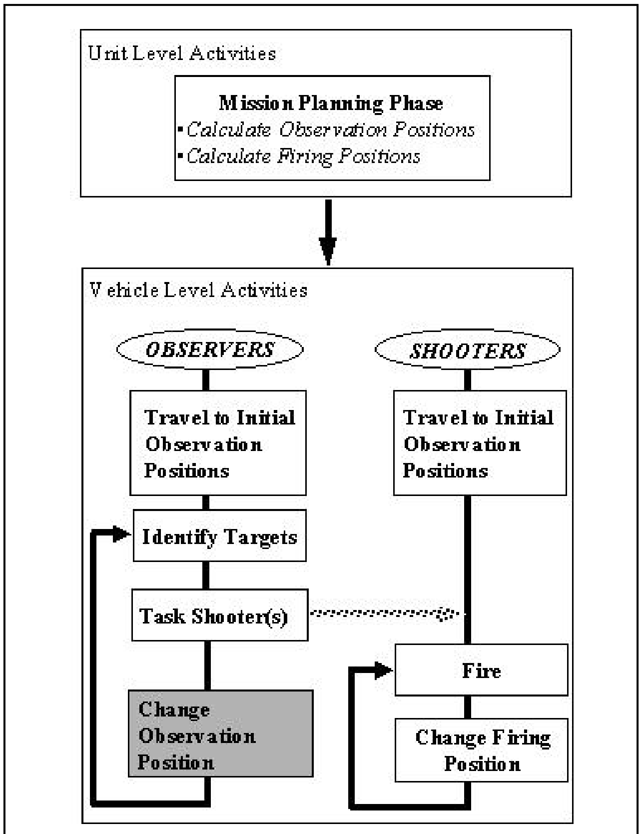

Figure 1. Process diagram for the OWF behavior

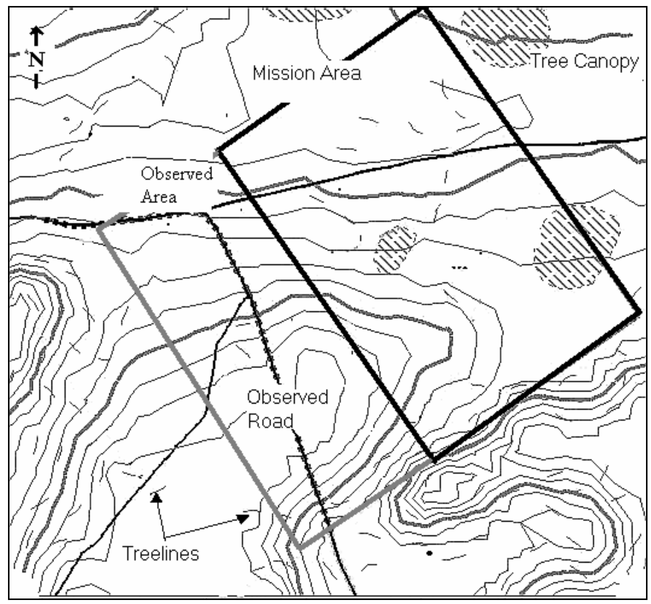

Figure 2. An OWF mission area and the observed road segment.

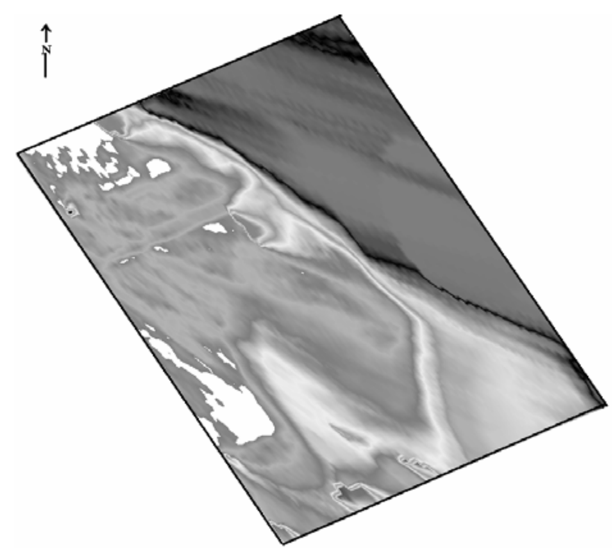

Figure 3. The visibility surface for the OFW mission area shown in the upper right of Figure 2.

2.1 PRE-MISSION PLANNING

Figure 1 shows a more detailed process diagram for the mission. It is divided into two major activities - unit level activities and vehicle level activities. Although this paper addresses only mission planning at the unit level communication to coordination with other units could be included as well. Picking appropriate observation and firing positions is crucial for the success of the OWF mission. Both types of points need to provide the user with an unobstructed view of the road segment , yet be near to potential concealment. In our research we consider the observation point as a doublet including an observation point and an associated concealed point. Finding the doublet involves constructing a visibility surface from the digital map of the battlefield. Suppose the OWF team is a assigned to protect road segment R containing the set of n points $\{r_1, r_2, r_3 \ldots r_n\}$. Let M be a potential OFW mission area. For any point m in the region M, let

$$V(m) = \frac{\sum_{k=1}^{n} \mathrm{LOS}(r_1, m)}{n} \tag{1}$$

where

surface depend on both the ground elevation and opaque features in both the mission area and observed area. In Figure 2, there are canopy regions and treelines that influence the shape of the visibility surface. We will exploit the surface irregularity to pick the observation doublet. Doublets occur near large jumps in the visibility surface. There are a number of ways to find these jumps - we use a Monte Carlo approach to select candidate points, calculate a surface gradient and use numerical ascent and descent methods find the elements of the doublet. Notice that this Monte Carlo approach does not find *optimal* points - but it finds *acceptable* points.

We use a similar procedure to find acceptable firing positions. In this case we describe a firing position with a triplet of points containing a firing point, a concealed point and a preparatory point. The preparatory point is partially obscured from the road segment. Rather than waiting for targets at the more exposed firing positions, shooters can wait at the preparatory positions.

Figure 4 shows two firing position triplets (F_1, P_1, H1) and (F_2, P_2, H_2). The observed road segment (not shown in this figure) is to the south of the figure. The first triplet is clustered around a building; the second triplet is clustered around a treeline. Notice that the hide points, H1 and H2, are on the northern side of terrain features that block line of sight to the observed road segment in the south.

The planning phase determines multiple firing and observation positions, allowing vehicles to move between pre-determine positions during the mission. Most of our current experiments involve units with a single scout observer and a single shooter which visit their points in random order so that their movements are not easily predicted by opposing forces. As we experiment with larger units, we may need to find other ways to assign the points.

2.2 Mission Execution

Once the planning is complete, the shooters and observers move into their initial positions. For the observers the initial position is an observation point. For the shooters, the initial position is a preparatory point. Following the diagram in Figure 1, the unit waits until a target has been identified by an observer. The observer tasks a specific shooter to move into position and fire on the target. To protect the unit from effective counter-attacks, the shooter fires then immediately changes firing positions. One of the uses of the triplet firing point structure is to allow robots to move between pre-computed concealed positions to get to their next firing position. A vehicle moving from firing position triplet FP_1 to FP_2 would follow the sequence of waypoints $\{F_1, H_1, H_2, P_2, F_2\}$. In future work, the route between H1 and H2 can be planned to optimize concealment, travel time or other factors. The observer may also change positions during the mission. The gray box in Figure 1 indicates this is an optional rather than required task.

At the present time, we are experimenting with units of 1 observer and 1 shooter; and 1 observer and 2 shooters. The observer can move between observation point and hiding points within the same doublet but does not change doublets once the mission starts. As our research continues we will add additional observers and shooters.

We are developing the OWF behavior using the One Semi Automated Forces Testbed (OTB) [4] simulation tool developed by the Simulation Training and Instrumentation Command (STRICOM – now the program executive office for simulation, training and instrumentation, PEO- STRI). In the next section we describe features of the baseline systems and some of the extensions we have developed to aid our robotic behavior work.

3. The OTB Simulation Tool

3.1 Baseline Features

OTB [6] is an interactive battlefield simulation tool developed by the Simulation Training and Instrumentation Command (STRICOM) that simulates the behavior of units, their vehicles, and their weapons systems to a level of realism sufficient for training and combat development. It provides users with the capability to create and control units ranging in size, from individual combatants and platforms through battalions. The simulation package also includes a representation of the physical environment, including terrain, diurnal cycle and weather, and its effect on simulated activities and behaviors.

OTB has many desirable features for developing and testing robotic behaviors. It is an easy-to-use, interactive tool that allows users to design test scenarios. Currently, there are several hundred different types of units that can be used in these scenarios. These units range in size from individual soldiers to battalions. The units include both air and ground systems and represent both U.S. and foreign systems. The actions of these units can be controlled by the user or, to a limited extent, controlled by OTB behavior algorithms. Users can add new units and behavior algorithms to the base systems to support specific projects. There are many terrain databases available for OTB. These terrain databases include U.S. Army installations such as Ft. Knox, Ft. Hood and the National Training Center as well as parts of Europe and Asia. In addition, commercial packages such as MultiGen Creator[1] can be used to provide 3-dimensional visualization of the terrain databases.

Unfortunately, OTB does have limitations as a tool for developing and testing robotic behaviors. These limitations

[1] MultiGen Creator is a trademark of the MultiGen-Paradigm Corporation, 2044 Concourse Drive San Jose, CA 95131.

can be grouped into two categories – terrain database limitations and entity behavior limitations.

Most of the terrain databases that are available for OTB have elevation posts spaced 30 -125 m apart. This results in a "smooth" terrain surface that does not accurately model the terrain encountered by a small vehicle. Many terrain features, such as trees, wooded areas, roads, rivers, and buildings are "layered" on top of the elevation grid as linear or polygonal abstract features. Although these abstract features do affect the activities of the simulated entities, they are not directly sensed by the sensory equipment attached to entities. It is difficult to examine the robustness of behaviors that involve autonomous mobility without including a model of how the driving sensors acquire information about the environment. Also, most OTB terrain databases do not contain ditches, holes, rocks, boulders, and other small obstructions that present significant obstacles for ground robots.

The current OTB mobility behavior algorithms assume a competent human driver is controlling the system. This driver model "perceives" and responds appropriately to obstacles in the terrain, updating the vehicle position and velocity several times a second. In fact, because the driver is assumed to be competent, most OTB terrain databases do not contain small mobility obstacles to stimulate the driving algorithms.

We cannot assume a competent driver for the Demo III program because a major research issue is the robustness of its driving algorithms. We have not fully investigated other behavior algorithms in OTB; however, many of the algorithms are trying to simulate *human* actions, so they may use information and intelligence not yet available to ground robots. In general, we would like to replace the OTB behavior algorithms with a better representation of robotic behavior.

3.2 ARL Extensions

We have extended the basic features of the OTB simulation code to better represent ground robotic features. Our work can be divided into three categories – terrain modifications and robot-specific modifications and aids for performing multiple experimental trials. The terrain modifications overcome some of the limitations of the terrain databases described in the previous section, providing the simulated robot with a rich environment containing both large and small obstructions that need to be sensed and incorporated into its mobility plan. There are many different approaches to modifying the OneSAF terrain databases to support mobility analysis for robotic vehicles, a detailed discussion of these modifications is found in Fields [7]. One tool of particular interest is the obstacle editor, documented in Fields and Haug [1]. This tool allows researchers to use the complexity of the terrain as an experimental parameter.

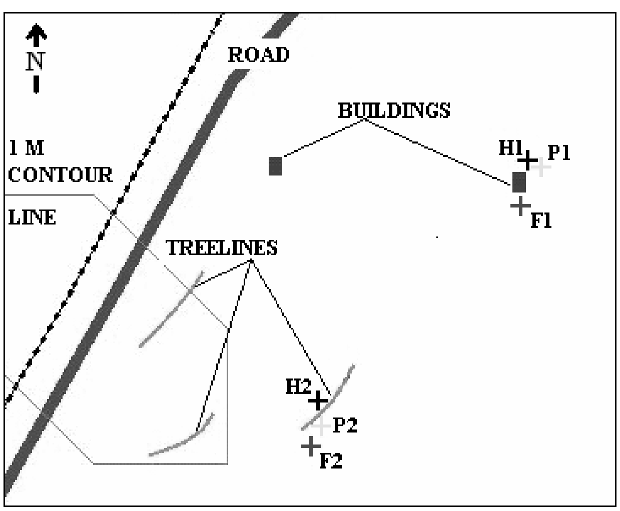

Figure 4. Two firing position triplets.

In addition to the obstacle editor, we developed algorithms of robotic driving perception and robotic mobility which are documented in reference 8. These algorithms model the perception and planning processes of the robot. The perception algorithms are "aware" of the mobility obstacles previously discussed. At each time step, the robot constructs a world model showing detected obstacles and features within a 50-m radius of the robot. The detection of a specific obstacle is a random variable whose probability distribution function is specified by the detectability parameters.

Thoroughly testing robotic behavior algorithms, such as the OWF algorithm described in the previous section, requires many experimental trials in which the robots must exercise the behavior algorithms in many different situations. The process of setting up and running each experimental trial can be very tedious. In our case, a user needs to specify a road segment to watch and an observation box for each experimental trial. Not all road segments are suitable – some offer too much or too little nearby cover for a realistic mission scenario. Using a line-of-sight analysis, researchers can find suitable locations for each trial. Once the road segment and observation box are picked, researchers need to set up the friendly and opposing forces and their tasks and run the experimental trial.

In our work, we have designed a tool, the experiment library, to allow researchers to run a series of OTB trials efficiently. Figure 5 shows the Experiment Editor window used to run the OWF experiments. It allows the researcher to set basic parameters for the series of experimental runs. In the top left corner, users enter a base filename which is used to create the data storage files for the experiments. Users may also specify a random number seed to control repeatability of the experimental trials. There are pull-down menus to select the OFW team and the opposing force. Currently, there are two OFW teams 1Observer:1 Shooter and 1 Observer: 2 Shooters available. The opposing forces are platoons of BDRMs or BMPs (see reference 1 for vehicle and unit descriptions). Finally, the users can restrict the experimental area to a rectangular region of the battlefield by entering the MaxX

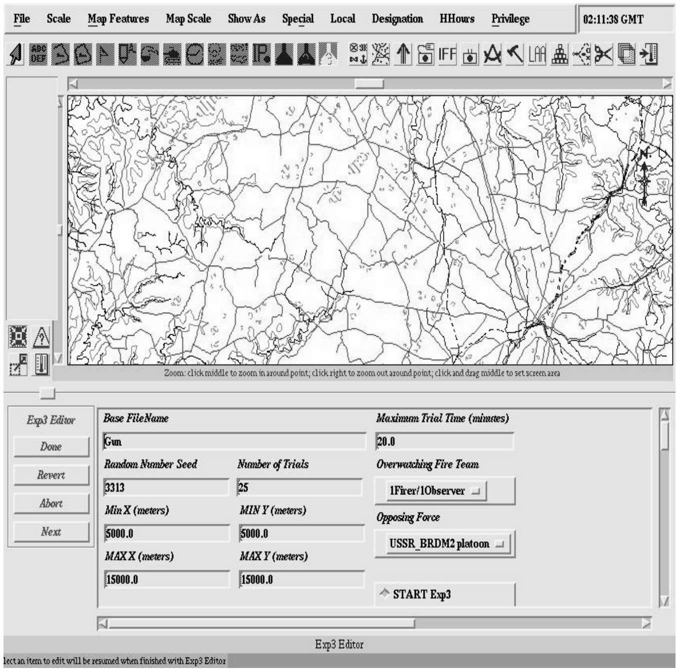

Figure 5. The Experiment editor.

MaxY, MinX and MinY parameters which can contain many possible road segments and observations areas.

The experiment library automatically selects appropriate road segments and observation areas for each trial. It creates the vehicles and run each trial scenario. Scenarios are terminated after one of the following conditions are satisfied: 1) the opposing force leave the observed road segment, 2) all the opposing force is destroyed 3) all of the robotic shooters or observers are destroyed or 4) the trial time exceeds the maximum allowed time specified with the experiment editor. the end of each trial, the experiment library closes the data files and destroys the current set of vehicles.

The experiment library has been very useful in developing the OWF algorithm. In addition to running complete experiments, it has allowed us to examine our methodology for picking firing and observation positions by generating hundreds of potential positions. In the future we also want use the same tool to study methods for generating concealed routes between the firing positions.

4. Extensions of the OWF behavior

Currently, we have experimented with the OWF behavior for a team of 1 observer and at most 2 shooters working on a complete map of the world. As our research continues, we will explore three issues. First, we need to examine the effectiveness of the basic OWF behavior. Using the experiment editor, we can collect data on how quickly enemy units are detected, the number of friendly and enemy units killed, and the amount of time the enemy unit spend on the observed road segment. Second, we need to determine the effect of uncertainty on the overall mission. Two other issues we plan to examine are larger teams and different command and control and/or human interaction paradigms.

What if the map is incomplete or inaccurate? The robots still need to find suitable positions to perform the mission. The visibility surface is not well-behaved - small changes in position can lead to large changes in visibility. The success of the OWF mission depends on being able to observe the road segment. If the real world does not agree with the map, there are two ways to continue the mission - use human operators or onboard perception systems to find the observed road segment. First a human operator could intervene and find a suitable position for the robot using information available from the reconnaissance sensors on-board the robot. Since the robots may wait a long time for the initial enemy contact, a human operator should have enough time to move the robots into their initial positions. However, once the enemy enters the observed area, there may not be enough time to reposition the robots. Repositioning reduces the probability of detection for the robots. They can remain at their initial position throughout the mission, but robot losses may increase.
Secondly, the robot could use perception technologies to find the observed road. Finding the observed road is not necessarily easy

As size of the OWF team increases, we need to develop effective strategies to partition the behavior into vehicle-level tasks. For instance, as additional shooters are added, a straightforward strategy is to assign each shooter a sector of responsibility. One issue with this approach is that the distribution of acceptable firing positions - there should be at least two firing positions in each sector to allow the shooters to change firing positions. Losing one or more robots may necessitate re-calculating sectors and firing positions. In contrast, voting schemes or market strategies to dynamically assign firing positions to shooters. These strategies tolerate fluctuations in the number of available robots; they may be an effective way to use a larger team. We will investigate voting schemes and market strategies in the next phase of this work.

Ultimately, a human operator needs to give the OWF team permission to use their weapons. If operators must grant permission for each individual shot, the behavior may be too unresponsive to be effective. On the other hand, if the operator gives firing permission as soon as the first enemy unit is identified, the robots' reconnaissance surveillance and target acquisition (RSTA) systems must be able to distinguish enemy units from any other vehicles using the observed road segment. We can study some of the human interaction issue by varying the amount of time it takes for the observers to task the shooters. This time delay represents the amount of time it takes for the human operator to receive and process information from the observer.

5. Conclusions

This research represents a preliminary analysis of an armed robotic mission. By assuming that the robotic vehicles are equipped with accurate sensors and that the digital map is an accurate representation of the battlefield, we can show that the OWF behavior algorithm allows a team of manned and unmanned systems to protect a road segment. There are still many issues that need to be explored for this behavior before we consider it ready for actual robotic platforms. An important issue is robust behavior performance given incomplete or inaccurate digital maps and less than perfect sensor information. Here the value of simulation to our behavior development effort becomes clear. We can gradually alter the quality of information available to the robots. Recently, we have begun to conduct experimental trials in which the map provides perfect information but the robots position is not known precisely. In the future, we need to add features to the world that are not present on the *a priori* map.

Developing tactical behaviors in a simulation has many benefits. As discussed in this report, using the enhanced OTB simulation to represent current UGV capabilities facilitates the development of behaviors that can be transitioned to current platforms. The simulations can also point the way to new technology developments and capabilities required to accomplish more complex behaviors. In the OWF research, we have identified some perception issues that are important for operating autonomously in an uncertain environment.

This research effort demonstrates that, with a realistic representation of an UGV and its environment, a computer simulation is a viable tool for building tactical behaviors for UGVs. The current project focused on a single team behavior that had to be designed from scratch using the simulated world to test and debug the algorithm. In our future research , we need to develop libraries of common skills and behaviors that can be combined into complex individual and group behaviors. As the library of common skills and behavior grows, development and testing time for complex behaviors may decrease because each of the common behaviors and skills will be well characterized.

References

[1] M. Fields and B Haug, "Developing a Chemical Reconnaissance Behavior for Unmanned Ground Vehicles Using the OneSAF Battlefield Simulation Tool", ARL-TR-2972, Army Research Laboratory, Aberdeen, Maryland, May 2003.

[2] Chen, S., T. Hsieh J. Kung and V. Beffa, "Autonomous Weapons",http://www-cse.stanford.edu/classes/cs201/Projects, 1996.

[3]Federation of American Scientists Military Analysis Network, "Smart Weapons", http://fas.org/man/dod-101/sys/smart/index.html,2003.

[4] Dudenhoeffer D., D. Bruemmer and M. Davis "Modeling and Simulation For Exploring Human-Robot Team Interaction Requirements", Proceedings of the 2001 Winter Simulation Conference 2001;

[5]Murphy, R and E. Rogers, "Human-Robot Interaction, Final Report for DARPA/NSF Study on Human-Robot Interaction", http://www.aic.nrl.navy.mil/hri/nsfdarpa/HRI-report-final.html,2001.

[6] Witman, R. and Harrison, C., "OneSAF: A Product Line Appraoch to Simulation", Technical Report, Contract Number DAAB07-01-C-C201. The Miter Corporation, 2001.

[7] M. Fields, "Modifying ModSAF terrain Databases to Support the Evaluation of Small Weapons Platforms in Tactical Scenarios", ARL-TR-1996, Army Research Laboratory, Aberdeen, Maryland, August 1999.

[8] M. Fields, "Designing a Behavior Development Environment to Support the Demo III Robotics Program", Proceedings of the SPIE Vol. 4364, AeroSense Session on Unmanned Ground Vehicle Technology, Orlando FL, April 7-8, 2000.

[10]Federation of American Scientists Military Analysis Network, "Rest-of-World Land Combat Systems", http://fas.org/man/dod-101/sys/land/row/index.html,2003.